Fermi National Accelerator Laboratory

FERMILAB-Conf-93/329-E

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Top Quark Search at CDF

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November 1993

Update of the talk presented at the *New Physics in New Experiments Meeting*, Kazimierz, Poland, May 1993

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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FERMILAB-CONF-93/329-E

TOP QUARK SEARCH AT CDF [1]

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ABSTRACT

The current status of the Top quark search at CDF is presented. A lower limit on the Top mass of 113 GeV has been established using the dilepton channel with the data collected during the 1988-89 and 1992-93 runs at $\sqrt{s} = 1.8$ TeV. Prospects for Top quark discovery during the 1993-94 run are also outlined.

1. Top Quark Production and Decay at the Tevatron

With the discovery of the Top quark the fermion sector of the three generation Standard Model will be completed. Apart from its necessity for theoretical consistency of the Standard Model, the existence of the Top quark is inferred by several measurements, such as the forward backward asymmetry in $Z \to b\bar{b}$ at LEP and the absence of flavor-changing neutral currents. An indirect value of the Top quark mass of $m_t = 164^{+16+18}_{-17-21} GeV$ has been estimated[1] by comparing the precision measurements of the Z boson resonance at LEP with electroweak calculations including radiative corrections. This method assumes that no new physics is present.

During the 1988-89 run, CDF collected 4.1 pb^{-1} and established[2] a lower limit on the Top quark mass of 91 GeV. Major upgrades (improving the muon coverage and introducing a Sillicon Vertex Detector) were done in the detector for the 1992-93 run and CDF collected 21.4 pb^{-1}.

The process $p\bar{p} \to t\bar{t}$ is the dominant process for Top quark production at the Fermilab Tevatron. The cross section is a steeply falling function of the Top quark mass varying from 30 pb at 120 GeV to 5 pb at 190 GeV. The Top quark is expected to decay into a W boson and a b-quark assuming no deviations from the Standard Model. So, the produced Top quark pairs have three possible decay channels, giving three different search methods:

1. The dilepton and two jets (the b-quark jets) in the final state, having a branching ratio of 4/81.
2. The single electron or muon plus three or four jets (the b-quark jets and the two jets coming from the hadronic decay of a W) in the final state, having a branching ratio of 24/81. Taus are not considered.
3. The six jet final state, having a branching ratio of 36/81.

[1] Update of the talk given at the Meeting "New Physics in New Experiments", Kazimierz, Poland, May 1993

2. The Dilepton Channel.

This is the cleanest channel but has the lowest branching ratio. Two high P_T ($P_T > 20GeV$) leptons (electrons or muons) with opposite signs for the electric charges and at least one of them isolated are required in this channel. A missing transverse energy $\not{E}_T > 25GeV$ and two jets are also required. For events with $\not{E}_T < 50GeV$ it is also required that the azimuthal angle between the E_T direction and the direction of the two leptons or the two jets be $\Delta\phi(\not{E}_T, l) > 20^0, \Delta\phi(\not{E}_T, l)) > 20^0$. There are two $e\mu$ events (see figure 1) and no dielectron nor dimuon events in the signal region. The most important backgrounds have been estimated to be WW, $Z \to \tau\tau$, $b\bar{b}$ processes and QCD or $W + jet$ processes with at least one misidentified lepton. The total expected background is 0.55±0.13 events.

The $t\bar{t}$ production cross section is given by $\sigma_{t\bar{t}} = N_{top}/L\epsilon_{top}$, where N_{top} is the number of observed events, L is the integrated luminosity and ϵ_{top} is the detection efficiency for the dilepton channel (which varies with the Top mass). The $95\%C.L.$ limit on $\sigma_{t\bar{t}}$ as a function of the Top mass is shown in figure 2 for the combination of the data collected during the 1988-89 and 1992-93 runs. In the figure are also shown the results of two theoretical calculations: the lower curve is the Next to Leading order calculation[3] and the higher curve is the Next-to-next to Leading order calculation[4]. Taking uncertainties into account and subtracting the expected background one obtains a lower limit in the Top mass of 113 GeV at the $95\%C.L.$.

3. Lepton and Jets Channel.

More than 19000 W events were selected by requiring a good electron (muon) with $E_T \geq 20GeV$ ($P_T \geq 20GeV$) and a missing transverse energy in the event $\not{E}_T \geq 20GeV$. The jet multiplicity distribution in the W sample was studied[5] with the 1988-89 CDF data and shown to be in good agreement with QCD calculations[6] within the theoretical uncertainties. A way of significantly reducing the QCD background is to ask for tagging a b-quark jet in the event. The jets were requiered to have $E_T \geq 15GeV$ and $|\eta| < 2.0$.

a. b-quark Tagging with Soft Leptons.

b-quark jets can be tagged identifying the leptons of the decay $b \to l$ ($l = e$ or μ) or $b \to c \to l$. For this purpose, leptons with $P_T > 2Gev/c$ are considered. The leptons from b decay are expected to have a soft spectrum ($< P_T > \approx 4GeV/c$ for $M_{top} \approx 120GeV/c^2$).

The efficiency of the soft electron algorithm was measured through a photon conversion sample and the efficiency of the soft muon algorithm was measured through the $J/\psi \to \mu^+\mu^-$ sample. Fake rates were determined through a sample of generic jets. The most important physics background is the generic heavy flavor

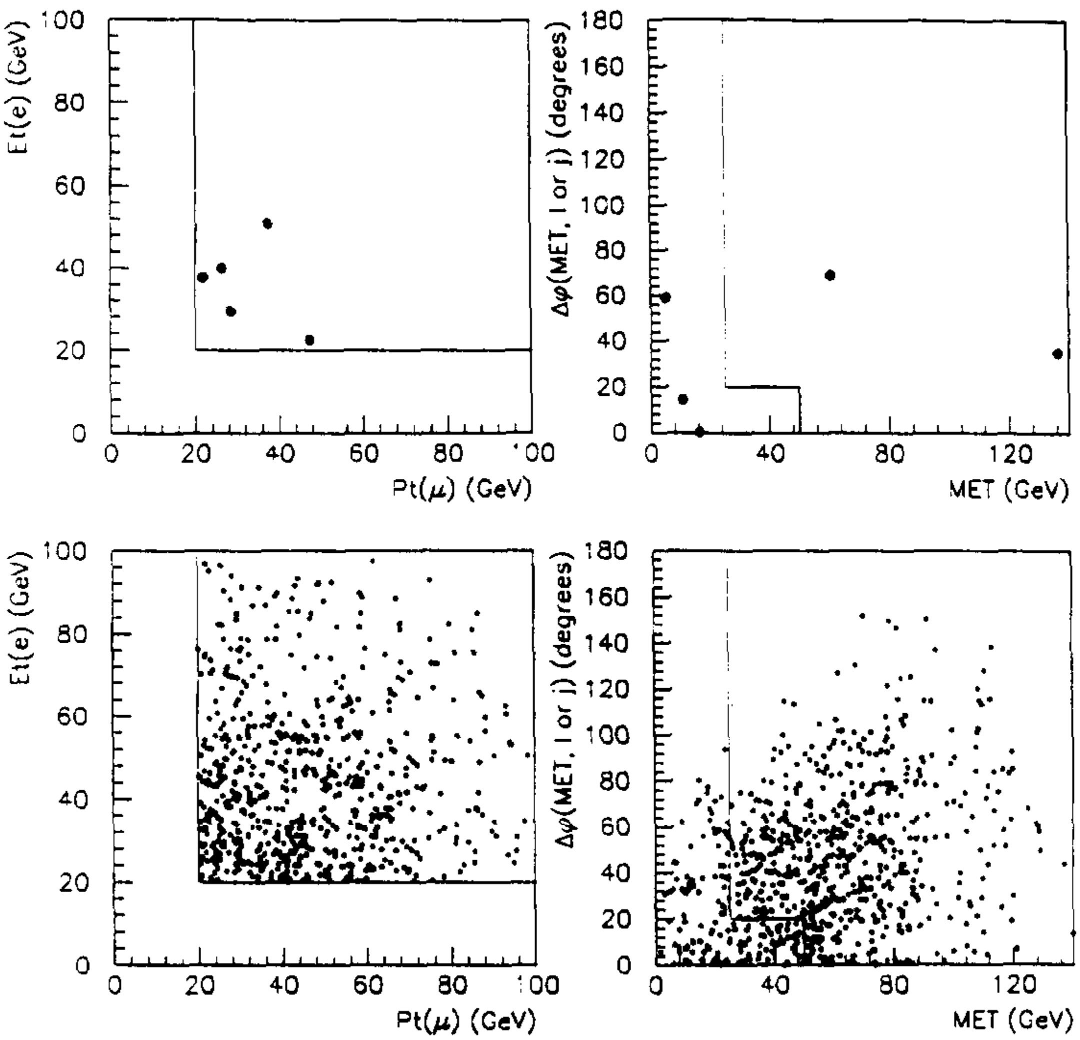

Figure 1: a) $E_T(e)$ vs $P_T(\mu)$, b)$Min(\Delta\phi(\not{E}_T, l), \Delta\phi(\not{E}_T, l))$ vs missing E_T for $e\mu$ data in the 1992-1993 run. There are two events in the signal region.c) and d) are the same plots as a) and b) but for $t\bar{t}$ Monte Carlo events witn $M_top = 140GeV/c^2$.

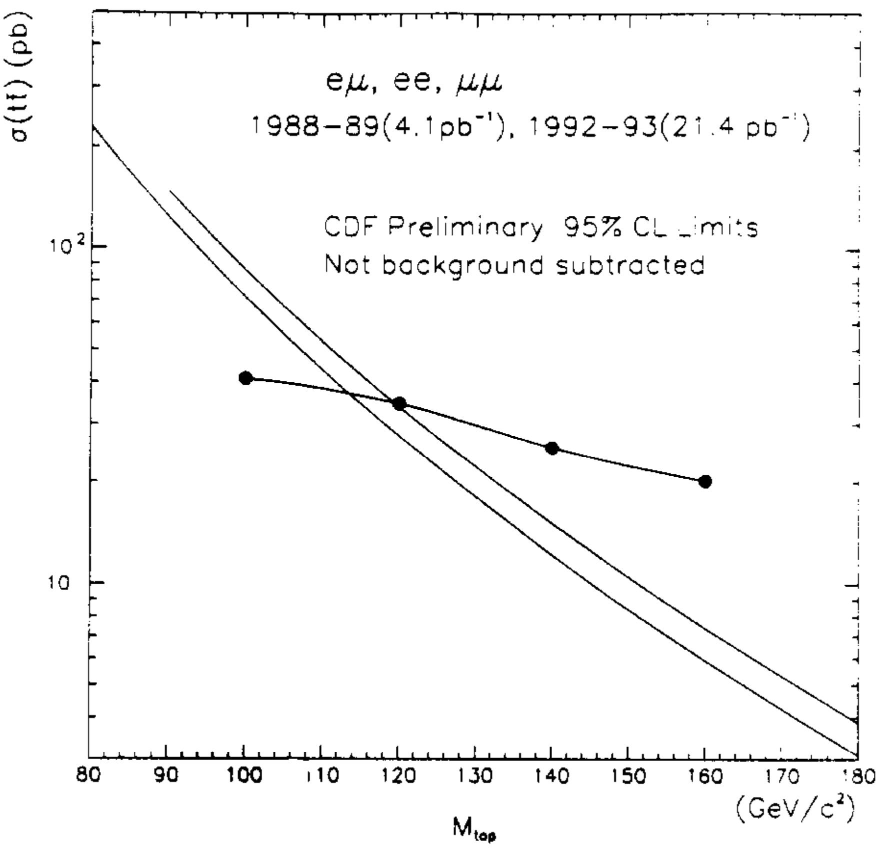

Figure 2: The experimental 95%$C.L.$ limit on $\sigma_{t\bar{t}}$ as measured in the dilepton channel (points) and two theoretical predictions.

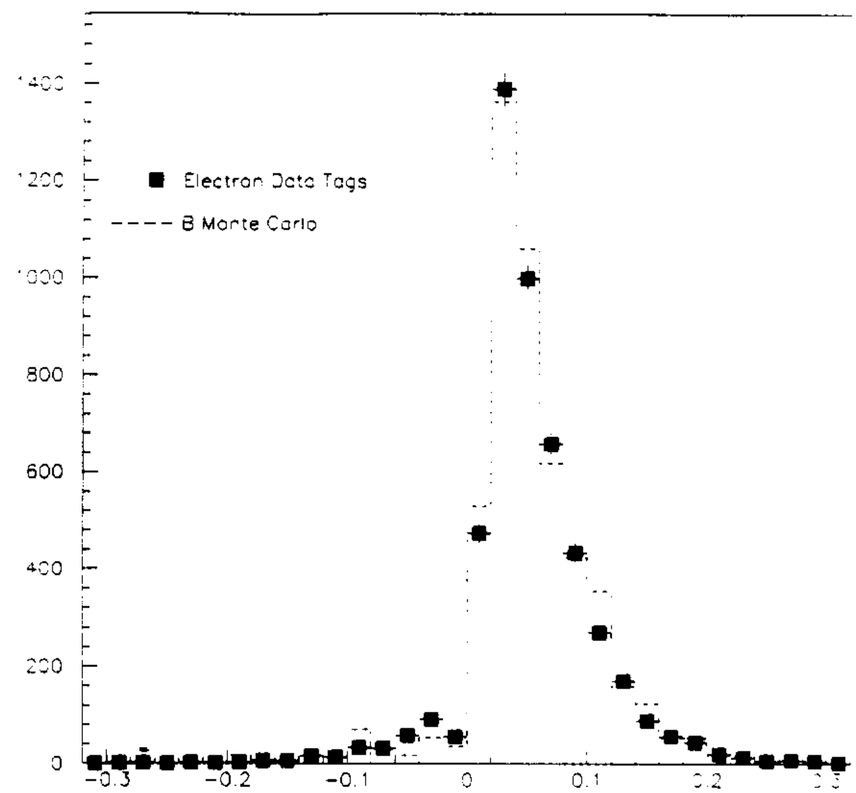

Figure 3: The $c\tau_{eff}$ distribution in the inclusive electron sample as measured by the SVX (points) compared to Monte Carlo (histogram).

production in association with a W boson.

Applying the soft lepton-identification algorithms to the W sample results in the number of events listed in table 1. Also listed in this table is the total background estimate. It can be seen that the number of events with soft leptons is in agreement with the expectations from the sum of misidentification and physics backgrounds within the statistical errors. Note that the amount of data analyzed in this channel corresponds to an integrated luminosity of 10 pb^{-1}.

Events tagged in $\int \mathcal{L}dt$=10.0 ± 1.0 pb^{-1}	$N_{jets} = 1$	$N_{jets} = 2$	$N_{jets} \geq 3$
Data	19	4	2
Background	17.8 ± 1.8	4.2 ± 0.4	1.8 ± 0.2
M_t = 140 GeV/c^2	0.23 ± 0.04	0.78 ± 0.14	2.0 ± 0.4

Table 1: Summary of Soft Lepton Analysis (SLT)

b. b-quark Tagging with the SVX.

Because of nonzero b lifetime, tracks from b decays may have a measured displacement from the primary vertex. The CDF Sillicon Vertex Detector[7] (SVX), with a tranverse impact parameter resolution of $\approx 40\mu m$ for stiff tracks, consists 4 layers situated concentrically right after the beam pipe. The pattern recognition of the tracks in the SVX starts with reconstructed tracks from the Central Tracking Chamber (CTC).

Displaced tracks measured with the SVX were used to reconstruct secondary vertices in a jet. Tracks consistent with K_s or Λ were removed. At least two good tracks with $P_T \geq 2GeV/c$ and impact parameter significance $d/\sigma_d \geq 3.0$ were required to form a secondary vertex with a 2 dimensional decay length significance $|L_{xy}|/\sigma_{L_{xy}} \geq 3.0$. Figure 3 shows the good agreement for the effective proper decay length between the inclusive electron CDF data and the Monte Carlo.

The largest contribution of the background in the Top signal region ($W+ \geq 3jets$) is expected to arise from mistags (tracking errors generate with equal probability tags with positive and negative decay length L_{xy}, whilst tags from heavy quark decays populate the positive L_{xy} region) and from W production in association with heavy flavors. Three events over an expected background of 1.0±0.2 events were observed in the signal region.

4. Six Jet Channel.

Besides having the largest branching ratio, the six jet decay mode has a larger detector acceptance. For high luminosities this channel could also also be added and used for mass determination[8].

5. Summary.

A summary on the Top acceptance and tagging efficiency for the different channels and for different values of the Top mass can be seen in table 2. A summary of the expected signal events and backgrounds is shown in table 3.

Top-quark Mass	120 GeV/c^2	140 GeV/c^2	160 GeV/c^2	180 GeV/c^2
$\sigma_{t\bar{t}}(pb)$	35.3	15.6	7.7	4.0
ϵ_{SVX}	$1.0 \pm 0.2\%$	$1.4 \pm 0.3\%$	$1.5 \pm 0.3\%$	$1.6 \pm 0.4\%$
ϵ_{SLT}	$1.0 \pm 0.2\%$	$1.3 \pm 0.2\%$	$1.4 \pm 0.3\%$	$1.6 \pm 0.3\%$
$\epsilon_{Dilepton}$	$0.48 \pm 0.07\%$	$0.65 \pm 0.09\%$	$0.76 \pm 0.11\%$	$0.84 \pm 0.13\%$

Table 2: Summary of Top Acceptance and Tagging Efficiency

Channel	SVX	SLT	Dilepton
$\int \mathcal{L}dt$ analysed	21.4 ± 2.1 pb^{-1}	10.0 ± 1.0 pb^{-1}	21.4 ± 2.1 pb^{-1}
Expected # events M_t = 120 GeV/c^2	7.3 ± 2.7	3.6 ± 0.7	3.7 ± 0.6
Expected # events M_t = 140 GeV/c^2	4.7 ± 1.8	2.0 ± 0.4	2.2 ± 0.3
Expected # events M_t = 160 GeV/c^2	2.3 ± 0.9	1.1 ± 0.2	1.3 ± 0.2
Expected # events M_t = 180 GeV/c^2	1.5 ± 0.6	0.7 ± 0.1	0.7 ± 0.1
Expected Background	1.0 ± 0.2	1.8 ± 0.2	0.55 ± 0.13
Observed Events	3	2	2

Table 3: Summary of Expected Signal Events and Backgrounds

The Tevatron will deliver a total luminosity of 100 pb^{-1} during the 1993-1994 run. With such luminosity and the techniques developed during the 1992-93 run, CDF should find the Top quark if its mass is not much higher than the average Standard Model estimations.

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